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(54) Improved Deposition Method

(57) This invention relates to transparent glass window structures of the type bearing a first coating 6 of infra-red reflective material, which is advantageously less than about 0.85 microns in thickness, wherein the observance of iridescence resulting from such a first coating is markedly reduced by the provision of a layer 4 of continuously varying refractive index between the glass 2 and the coating 6, such that the refractive index increases continuously from the glass to the first coating, thereby preventing the observation of iridescence. The coatings are applied by passing the substrate through a reaction zone in parallel with a reactive gas mixture which contains components for forming the two coatings, wherein the reaction to form the first coating proceeds more rapidly. A particular advantage of the invention is its efficacy with clear and lightly tinted glasses wherein the problem of iridescent color has had its greatest commercial impact.

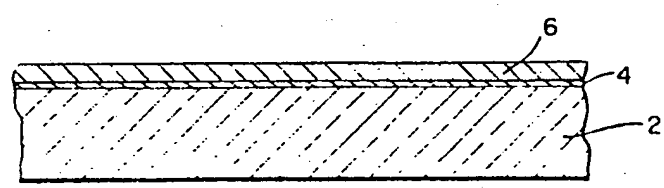

FIG. 2

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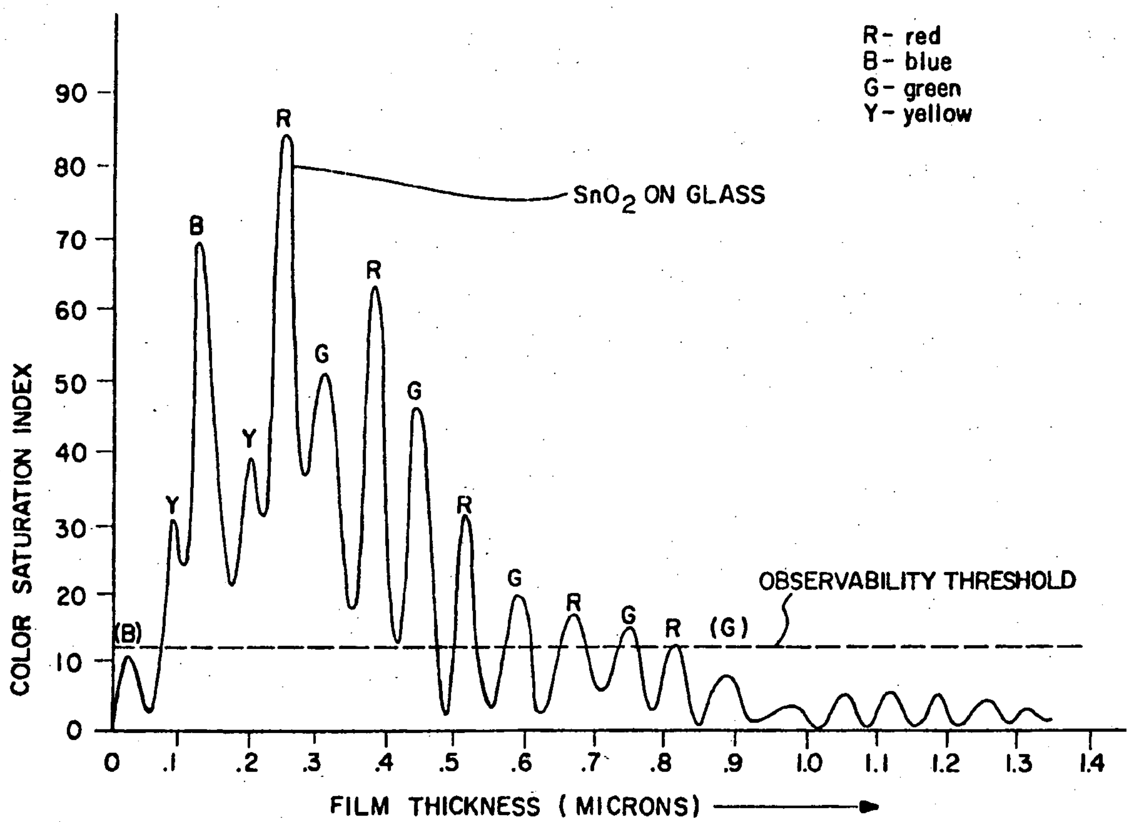
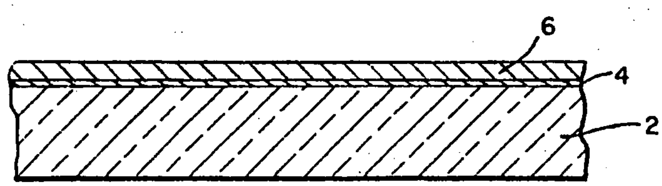


R- red
B- blue
G- green
Y- yellow
SnO2 ON GLASS
OBSERVABILITY THRESHOLD
COLOR SATURATION INDEX
0
10
20
30
40
50
60
70
80
90
(B)
Y
B
Y
R
G
R
G
R
G
R
G
R
(G)
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
FILM THICKNESS (MICRONS)

FIG. 1



6
4
2

FIG. 2

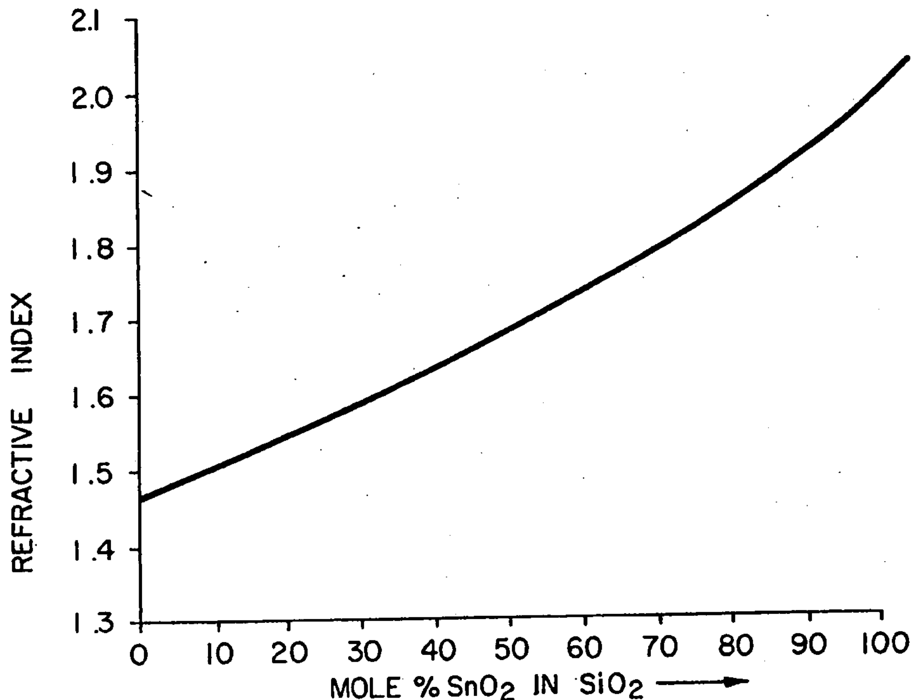

REFRACTIVE INDEX
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
0
10
20
30
40
50
60
70
80
90
100
MOLE % SnO_2 IN SiO_2

FIG. 3

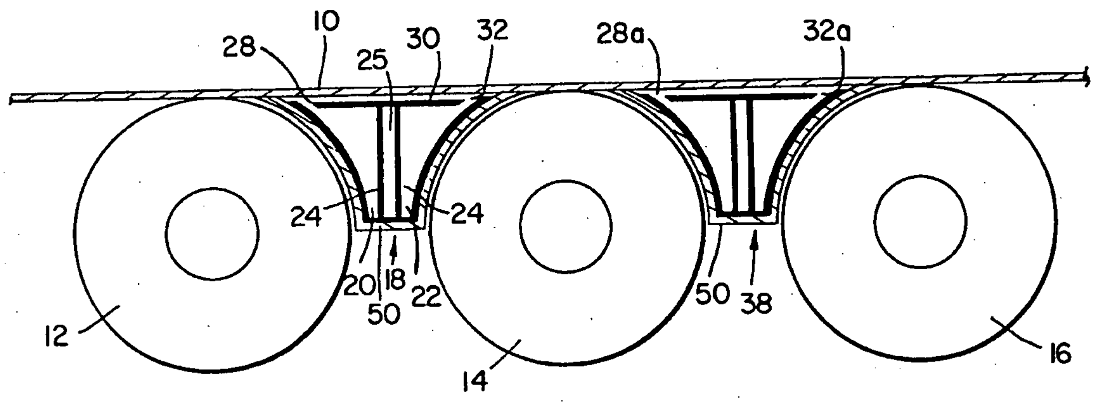

10
28
25
30
32
28a
32a
24
24
20
18
50
22
50
38
12
14
16

FIG. 4

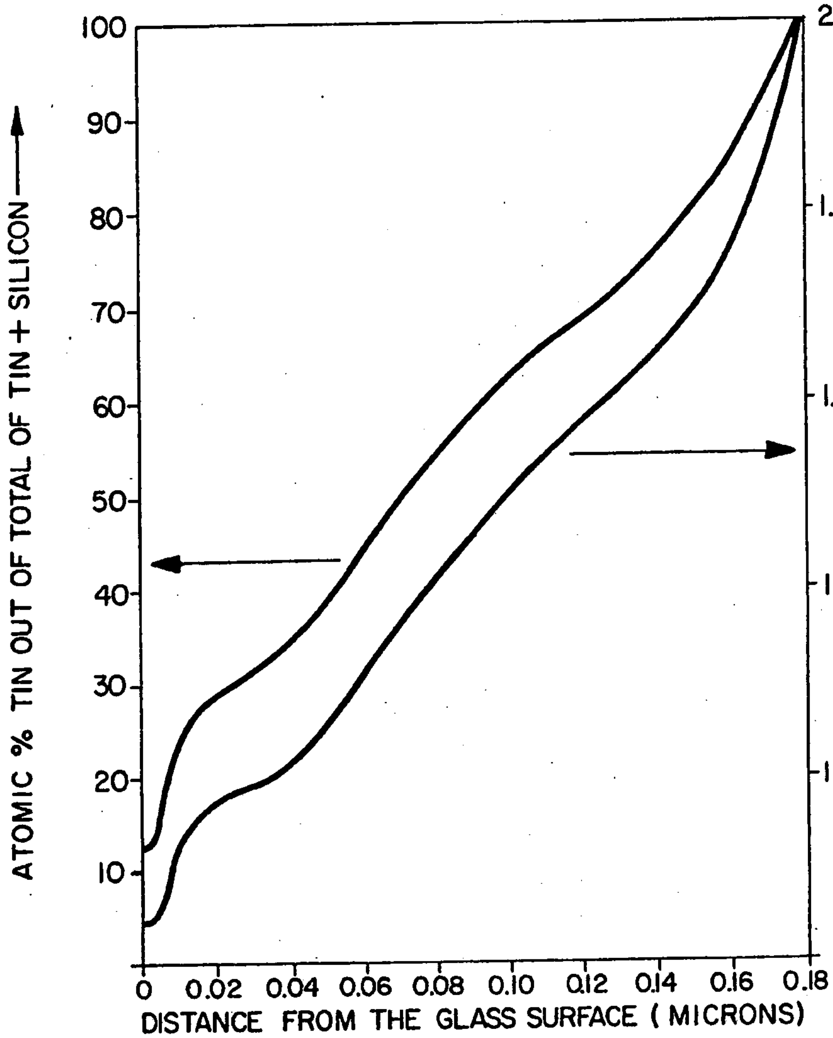

ATOMIC % TIN OUT OF TOTAL OF TIN + SILICON
100
90
80
70
60
50
40
30
20
10
2.0
1.9
1.8
1.7
1.6
1.5
REFRACTIVE INDEX
0 0.02 0.04 0.06 0.08 0.10 0.12 0.14 0.16 0.18
DISTANCE FROM THE GLASS SURFACE (MICRONS)

FIG. 5

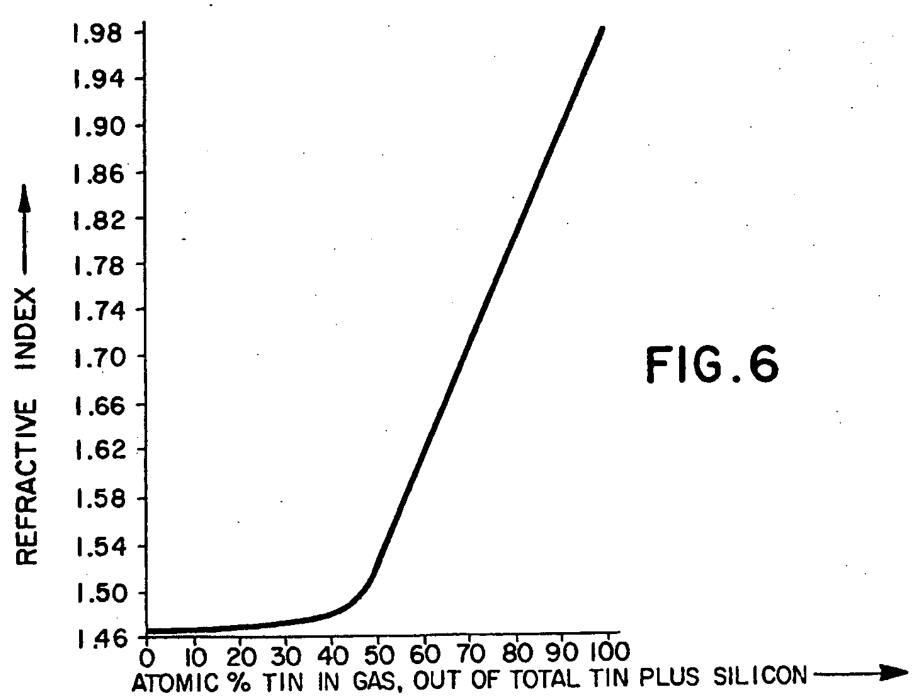

REFRACTIVE INDEX
1.98
1.94
1.90
1.86
1.82
1.78
1.74
1.70
1.66
1.62
1.58
1.54
1.50
1.46
0 10 20 30 40 50 60 70 80 90 100
ATOMIC % TIN IN GAS, OUT OF TOTAL TIN PLUS SILICON

FIG. 6

SPECIFICATION
Improved Deposition Method

Backgr und of the Inv nti n

This invention relates to glass structures bearing a thin, functional, inorganic coating (e.g. a coating of tin oxide forming means to promote reflectivity of infra-red light) which structures have improved appearance as a consequence of reduced iridescence historically associated with said thin coatings, and methods for achieving the aforesaid structures.

Glass and other transparent materials can be coated with transparent semiconductor films such as tin oxide, indium oxide or cadmium stannate, in order to reflect infra-red radiation. Such materials are useful in providing windows with enhanced insulating value (lower heat transport), e.g. for use in ovens, architectural windows, etc. Coatings of these same materials also conduct electricity, and are employed as resistance heaters to heat windows in vehicles in order to remove fog or ice.

One objectionable feature of these coated windows is that they show interference colors (iridescence) in reflected light, and, to a lesser extent, in transmitted light. This iridescence has been a serious barrier to widespread use of these coated windows (see, for example, America Institute of Physics Conference Proceeding No. 25, New York, 1975, Page 288).

In some circumstances, i.e. when the glass is quite dark in tone (say, having a light transmittance of less than about 25%) this iridescence is muted and can be tolerated. However, in most architectural wall and window applications, the iridescent effect normally associated with coatings of less than about 0.75 microns is aesthetically unacceptable to many people (See, for example, U.S. Patent 3,710,074 to Stewart).

Iridescent colors are quite a general phenomenon in transparent films in the thickness range of about 0.1 to 1 micron, especially at thicknesses below about 0.85 micron. Unfortunately, it is precisely this range of thickness which is of practical importance in most commercial applications. Semiconductor coatings thinner than about 0.1 micron do not show interference colors, but such thin coatings have a markedly inferior reflectance of infra-red light, and a markedly reduced capacity to conduct electricity.

Coatings thicker than about 1 micron also do not show visible iridescence in daylight illumination, but such thick coatings are much more expensive to make, since larger amounts of coating materials are required, and the time necessary to d posit the coating is correspondingly longer. Furthermore, films thicker than 1 micron have a tend ncy to show haze, which arises from light scattering from surface irregularities, which are larger on such films. Also, such films show a greater tendency to crack, under thermal stress, because of diff rential thermal expansion.

As a result of these technical and economic constraints, almost all pres nt c mmercial production of such coated glass articles comprise films in th thickness rang of about 0.1 to 0.3 microns, which display pronounced iridescent colors. Almost no architectural use of this coated glass is made at present, despite the fact that it would be cost-effective in conserving energy to do so. For example, heat loss by infra-red radiation through the glass areas of a heated building can approximate about one-half of the heat loss through uncoated windows. The presence of iridescent colors on these coated glass products is a major reason for the failure to employ these coatings.

Co-pending United States Application, S.N. 784,542, discloses means to reduce this iridescence to unobservably small values, by means of an additional layer or layers placed in register with the main coating, including a gradient-type coating. The present disclosure is directed primarily toward improved means for forming such a gradient-type anit-iridescent layer.

Summary of the Invention

It is one object of the present invention to provide means to eliminate the visible iridescence from semi-conducting thin film coatings on glass, while maintaining their desirable properties of visible transparency, infra-red reflectivity, and electrical conductivity.

Another object of the present invention is to achieve the above goals without increasing the cost of production significantly over the cost of using ordinary iridescent films.

Another object of the present invention is to achieve the above aims with a process which is continuous and fully compatible with modern manufacturing processes in the glass industry.

A further object of the present invention is to achieve all of the above goals with products which are highly durable and stable to light, chemicals and mechanical abrasion.

Another object is to achieve all of the above goals using materials which are sufficiently abundant and readily available to permit widespread use.

A further object of the invention is to provide means to reduce the total amount of light reflected from the coated surface of glass and thereby increase the total transmission of light by the glass.

Another object of the invention is to provide a glass structure comprising a compound coating wherein an outer coating is formed of an infra-red reflecting surface of about 0.7 micron or less and wherein an inner coating forms means for (a) reducing haze on the coated glass and, simultaneously and independ ntly (b) reducing the irid scence of the glass structure.

A further object of the invention is to provide a glass structure having the non-iridescent characteristics referr d to above which structure is characterized by a gradual change in coating

composition between glass and said outer coating.

Other objects of th inv ntion are to provide novel apparatus and processes which are suitable for making the above identified novel products and, indeed, which are suitable for use in making coatings of gradually changing compositions and from gaseous reactants whether or not such coating be on glass or some other substrate and whether or not such coatings comprise a maximum amount of one component within or at an extremity of the depth of the coating structure.

Other objects of the invention will be obvious to those skilled in the art on reading the instant invention.

The invention utilizes the formation of layers of transparent material between the glass and the semiconductor film. These layers have refractive indices intermediate between those of the glass and the semi-conductor film. With suitable choices of thickness and refractive index values of these intermediate layers, it has been discovered that the iridescent colors can be made too faint for most human observers to detect, and certainly too faint to interfere with widespread commercial use even in architectural applications. Suitable materials for these intermediate layers are also disclosed herein, as well as processes for the formation of these layers.

In the preferred form of the invention, these intermediate layers blend together continuously to form a graded layer in which the refractive index varies, preferably in a smoooth transition, as one moves through the layer away from the glass toward the semiconductor coating, from a value at the glass surface matching the index of the glass, to refractive index value matching that of the overlying semiconductor film, at a point proximate to that overlying film.

A coating with refractive index varying through its thickness may be produced by a novel method disclosed herein, in which a gas mixture with components of different reactivities, flows along the surface of a moving glass substrate.

Methods and Assumptions

It is believed desirable, because of the subjective nature of color perception, to provide a discussion of the methods and assumptions which have been used to evaluate the invention disclosed herein. It should be realized that the application of much of the theory discussed below is retrospective in nature because the information necessarily is being provided in hindsight, i.e. by one having a knowledge of the invention disclosed herein.

In order to make a suitable quantitative evaluation of various possible constructions which suppress iridescent colors, the intensiti s of such colors were calculated using optical data and color perception data. In this discussion, film layers are assumed to be planar, with uniform thickness and uniform refractive index within each layer. The r fractive index changes are taken to be abrupt at the planar interfaces between adjacent film layers. A continuously varying refractive index may be modelled as a sequence of a very large number of very thin layers with closely spaced refractive indices. Real refractive indices are used, corresponding to negligible absorption losses within the layers. The reflection coefficients are evaluated for normally incident plane waves of unpolarized light.

Using the above assumptions, the amplitudes for reflection and transmission from each interface are calculated from Fresnel's formulae. Then these amplitudes are summed, taking into account the phase differences produced by propagation through the relevant layers. These results have been found to be equivalent to the Airy formulae (See, for example, *Optics of Thin Films*, by F. Knittl, Wiley and Sons, New York, 1976) for multiple reflection and interference in thin films, when those formulae were applied to the same cases.

The calculated intensity of reflected light has been observed to vary with wavelength, and thus is enhanced in certain colors more than in others. To calculate the reflected color seen by an observer, it is desirable first to specify the spectral distribution of the incident light. For the purpose, one may use the International Commission on Illumination Standard Illuminant C, which approximates normal daylight illumination. The spectral distribution of the reflected light is the product of the calculated reflection coefficient and the spectrum of Illuminant C. The color hue and color saturation as seen in reflection by a human observer, are then calculated from this reflected spectrum, using the uniform color scales such as those known to the art. One useful scale is that disclosed by Hunter in *Food Technology*, Vol. 21, pages 100—105, 1967. This scale has been used in deriving the relationship now to be disclosed.

The results of calculations, for each combination of refractive indices and thicknesses of the layers, are a pair of numbers, i.e. "a" and "b". "a" represents red (if positive) or green (if negative) color hue, while "b" describes a yellow (if positive) or blue (if negative) hue. These color hue results are useful in checking the calculations against the observable colors of samples including those of the invention. A single number, "c", represents the "color saturation": $c=(a^2+b^2)^{1/2}$. This color saturation index, "c", is directly related to the ability of the eye to detect the troublesome iridescent color hues. When the saturation index is below a certain value, one is not able to see any color in the reflected light. The numerical value of this threshold saturation of observability depends on the particular uniform color scale used, and on the viewing conditions and level f illuminati n (see, for example, R. S. Hunter, *The Measurement of Appearance*, Wiley and Sons, N w York, 1975, for a review of numerical color scales).

In order to establish a basis for comparison of structures a first series of calculations was carried out to simulate a single semiconductor layer on

glass. The refractive index of the semiconductor layer was taken at 2.0, which is a value approximating tin xide, indium oxide, or cadmium stannat films. The value 1.52 was used for the glass substrate; this is a value typical of commercial window glass. The calculated color saturation values are plotted in Figure 1 as a function of the semiconductor film thickness. The color saturation is found to be high for reflections from films in the thickness range 0.1 to 0.5 microns. For films thicker than 0.5 micron, the color saturation decreases with increasing thickness. These results are in accord with qualitative observations of actual films. The pronounced oscillations are due to the varying sensitivity of the eye to different spectral wavelengths. Each of the peaks corresponds to a particular color, as marked on the curve (R=red, Y=yellow, G=green, B=blue).

Using these results, the minimum observable value of color saturation was established by the following experiment: Tin oxide films with continuously varying thickness, up to about 1.5 microns, were deposited on glass plates, by the oxidation of tetramethyltin vapor. The thickness profile was established by a temperature variation from about 450°C to 500°C across the glass surface. The thickness profile was then measured by observing the interference fringes under monochromatic light. When observed under diffused daylight, the films showed interference colors at the correct positions shown in Figure 1. The portions of the films with thicknesses greater than 0.85 micron showed no observable interference colors in diffused daylight. The green peak calculated to lie at a thickness of 0.88 micron could not be seen. Therefore, the threshold of observability is above 8 of these color units. Likewise, the calculated blue peak at 0.03 micron could not be seen, so the threshold is above 11 color units, the calculated value for this peak. However, a faint red peak at 0.81 micron could be seen under good viewing conditions, e.g. using a black velvet background and no colored objects in the field of view being reflected, so the threshold is below the 13 color units calculated for this color. We conclude from these studies that the threshold for observation of reflected color is between 11 and 13 color units on this scale, and therefore we have adopted a value of 12 units to represent the threshold for observability of reflected color under daylight viewing conditions. In other words, a color saturation of more than 12 units appears as a visibly colored iridescence, while a color saturation of less than 12 units is seen as neutral.

It is believ d that there will be little objection to commercialization of products having color saturation values of 13 or below. However, it is much preferred that the value be 12 or below and, as will appear in more detail hereinafter, there appears to be no practical reason why the most advantageous products acc rding to the invention, e.g. those characteriz d by wholly color-free surfaces, i. . bel w about 8, cannot be made economically.

A value of 12 or less is indicative of a reflection which does not distort the color of a r flected image in an observable way. This threshold value of 12 units is taken to be quantitative standard with which one can evaluate the success or failure of various multilayer designs, in suppressing the iridescence colors.

Coatings with a thickness of 0.85 micron or greater have color saturation values less than this threshold of 12, as may be seen in Figure 1. Experiments confirm that these thicker coatings do not show objectionable iridescence colors in daylight illumination.

Use of an Interlayer of Graduated Refractive Index

It has been discovered that a film intermediate between the glass substrate and a semiconductor layer can be built up of a graded composition, e.g. gradually changing from a silica film to a tin oxide film. Such a film may be pictured as one comprising a very large number of intermediate layers. Calculations have been made of reflected color saturation for a variety of refractive index profiles between glass of refractive index $n=1.52$ and semiconductor coatings of refractive index $n=2.0$. For transition layers thicker than about 0.15 micron, the calculated color saturation index is usually below 12, i.e. neutral to the eye, and, for, transitions more than about 0.3 microns the color is always undetectable. The exact shape of the refractive index profile has very little effect on these results, provided only that the change is gradual through the graded layer.

What Materials can be Used

A wide range of transparent materials are among those which can be selected to make products meeting the aforesaid criteria by forming anti-iridescent undercoat layers. Various metal oxides and nitrides, and their mixtures have the correct optical properties of transparency and refractive index. Table A lists some mixtures which have the correct refractive index range between glass and a tin oxide or indium oxide film. The weight percents necessary can be taken from measured refractive index versus composition curves, or calculated from the usual Lorentz-Lorenz law for refractive indices of mixtures (Z. Knittl, *Optics of Thin Films*, Wiley and Sons, New York, 976, Page 473), using measured refractive indices for the pure films. This mixing law generally gives sufficiently accurate interpolations for optical work, although the calculated refractive indices are sometimes slightly lower than the measured values. Film refractive indices also vary somewhat with deposition method and conditions employed.

Figure 3 gives a typical curve of refractive ind x versus composition f r the important case of silicon dioxid -tin dioxide mixtures.

Table A.

Some combinations of compounds yielding

transparent mixtures whose refractive indices span the range from 1.5 to 2.0

SiO_2	SnO_2
SiO_2	Si_3N_4
SiO_2	TiO_2
SiO_2	In_2O_3
SiO_2	Cd_2SnO_4

Process for Forming Films

Films can be formed by simultaneous vacuum evaporation of the appropriate materials of an appropriate mixture. For coating of large areas, such a window glass, chemical vapor deposition (CVD) at normal atmospheric pressure is more convenient and less expensive. However, the CVD method requires suitable volatile compounds for forming each material. Silicon dioxide can be deposited by CVD from gases such as silane, SiH_4, dimethylsilane $(CH_3)_2SiH_2$, etc. Liquids which are sufficiently volatile at room temperature are almost as convenient as gases; tetramethyltin is such a source for CVD of tin compounds, while $(C_2H_5)_2SiH_2$ and $SiCl_4$ are volatile liquid sources for silicon.

A continuously graded layer of mixed silicon-tin oxide may be built up during a continuous CVD coating process on a continuous ribbon of glass by the following novel procedure. A gas mixture is caused to flow in a direction parallel to the glass flow, under (or over) the ribbon of hot glass, as shown, for example, in Figure 4. The gas mixture contains an oxidizable silicon compound, an oxidizable tin compound, and oxygen or other oxidizing gas. The compounds are chosen so that the silicon compound is somewhat more quickly oxidized than is the tin compound, so that the oxide deposited on the glass where the gas mixture first strikes the hot glass surface, is mainly composed of silicon dioxide, with only a small percentage of tin dioxide. The proportions of silicon and tin compounds in the vapor phase are adjusted so that this initially deposited material has a refractive index which closely matches that of the glass itself. Then, as the gas continues in contact with the glass surface, the proportion of tin oxide in the deposited film increases, until at the exhaust end of the deposition region, the silicon compound has been nearly completely depleted in the gas mixture, and the deposit formed there is nearly pure tin oxide. Since the glass is also continually advancing from the relatively silicon-rich (initial) deposition region to a relatively tin-rich (final) region, the glass receives a coating with a graded refractive index varying continuously through the coating thickness, starting at the glass surface with a value matching that of glass, and ending at its outer surface, with a value matching that of tin oxide. Subsequent deposition regions, indicated in Figure 3, can then be used to build up further layers of pure tin oxide, or layers of tin oxide doped, for example, with fluorine.

A suitable gas mixture for this purpose, preferably includes the oxidizable silicon compounds, 1,1,2,2,-tetramethyldisilane ($HMe_2SiSiMe_2H$); 1,1,2,-trimethyldisilane $H_2MeSiSiMe_2H$, and/or 1,2, dimethyldisilane ($H_2MeSiSiMeH_2$) along with tetramethyltin (Me_4Sn). It has been found that the initially deposited film is silicon-rich, and has a refractive index close to that of glass, while the latter part of the deposit is almost pure tin oxide.

The Si-H bonds in the above-disclosed silicon compounds are highly useful in the process, since compounds without Si.H bonds, such as tetramethylsilane Me_4Si, or hexamethyldisilane $Me_3SiSiMe_3$, are oxidized more slowly than is tetramethyltin, and the initial deposit is mainly tin oxide, and the latter part of the deposit is mainly silicon dioxide. In such a case, i.e. when one is using compounds such as Me_4Si, one may flow the gas and glass in *opposite* directions in order to achieve the desired gradation of refractive index, provided the gas flow is faster than the glass flow. However, the preferred embodiment is to use the more easily oxidizable silicon compounds, and concurrent gas and glass flow directions.

It is also desirable, in forming coatings wherein the composition varies monotonically with distance from the substrate, that the silicon compounds have a Si-Si bond as well as the Si-H bond. For example, a compound containing Si-H but not SiSi bonds, dimethylsilane Me_2SiH_2, along with tetramethyltin, produces an initial deposit of nearly pure tin oxide, which then becomes silicon-rich at an *intermediate* time and finally becomes tin-rich still later in the deposition. Although Applicant does not wish to be bound by the theory, it is believed that the Si—Si—H arrangement facilitates rapid oxidation by an initial thermally induced decomposition in which the hydrogen migrates to the neighbouring silicon

$$HMe_2Si\text{-}SiMe_2H \rightarrow Me_2SiH_2 + Me_2Si.$$

The reactive dimethylsilylene Me_2Si species is then rapidly oxidized, releasing free radicals such as hydroxyl (OH), which then rapidly abstract hydrogen from the Si-H bonds, thus creating more reactive silylene radicals, forming a chain reaction. The tetramethyltin is less reactive to these radicals, and thus mainly enters into the later stages of the oxidation. The Me_2SiH_2 lacks the rapid initial decomposition step, and thus, cannot begin oxidation until after some tetramethyltin has decomposed to form radicals (CH_3, OH, O, etc.) which then preferentially attack the Me_2SiH_2, at intermediate times, until the Me_2SiH_2 is consumed, after which stage the oxidation of tetramethyltin becomes dominant again.

It is preferred to have at least two methyl groups in the disilane compound, since the disilanes with one or no methyl substituents are spontaneously flammable in air, and thus must be pre-mixed with an inert gas such as nitrogen.

Other hydrocarbon radicals, such as ethyl, propyl, etc., may replace methyl in the above

compounds, but the methyl ones are more volatile and are preferred.

Higher partially alkylated polysilanes, such as polyalkyl-substituted trisilanes r tetrasilanes, function in a way similar to the disilanes. However, the higher polysilanes are harder to synthesize, and less volatile than the disilanes, which are therefore preferred.

When the initial deposition of the silica-tin oxide films contain less than about 40% of tin oxide, there will be little or no haze created at the interface of the glass substrate and the coating thereover. If it, for some reason, is desired to start the gradient above about 30% of tin oxide, it is preferable to have the glass coated with a haze-inhibiting layer, i.e. silicon dioxide. Such a haze-inhibiting layer may be very thin, e.g. in the nature of 25 to 100 angstroms.

In the Drawings

Figure 1 is a graph illustrating the variation of calculated color intensity of various colors with semiconductor film thickness.

Figure 2 illustrates, schematically and in section, a non-iridescent coated glass constructed according to the invention, with an anti-iridescent interlayer of continuously-varying composition according to the invention.

Figure 3 is a graph indicative of a typical gradient of refractive indices, idealized, and representing the gradual transition from 100% SiO_2 to 100% SnO_2.

Figure 4 is a section, somewhat simplified to facilitate the description thereof of, a novel apparatus of the type convenient for use in the process of the invention.

Figure 5 illustrates the experimental measurement of the gradient in chemical composition of a silica-tin oxide gradient zone prepared according to the invention.

Figure 6 shows an observed variation of the refractive index of the initial deposit of SiO_2-SnO_2 at the glass surface, as a function of gas composition.

Figure 4 illustrates a section of a lehr in a float glass line. The structure of the lehr itself is not shown for purposes of clarity. The hot glass 10, e.g. about 500—600°C, is carried on rollers 12, 14 and 16 through the lehr. Between rollers 12 and 14 is positioned gas duct assembly 18 which comprises a gas inlet duct 20 and a gas outlet duct 22. Between ducts 22 and 20 and separated therefrom by heat exchanging wall members 24 is a duct 25 forming means to carry a heat exchange fluid, which, in turn forms means to cool gas exhaust from duct 22 and to heat gas flowing through duct 20. The temp rature of the heat exchange fluid is maintained at a sufficiently low temperature s that coating does not take place on the surface of the inlet duct.

Gas entering inlet 20 trav ls through a slit-like opening 28, thence along a reaction zone formed by the top surface 30 of duct assembly 18 and the lower surface of glass sheet 10. Upon reaching a second slit-like opening 32, the remaining gas is exhausted through duct 22. It is during the passage of the gas along the lower surface of glass sheet 10 that a gradient coating is form d by the selective depletion of one of the reactants at different points along the length of the deposition zone between rollers 12 and 14.

In the apparatus of Figure 4 a second gas duct assembly 38 is used to complete the deposition of a coating, e.g. by adding a fluoride-doped tin oxide coating to the pre-deposited gradient coating. Again, it is convenient to have gas enter the upstream port 28a and leave the downstream port 32a.

The ducting is suitably formed of corrosion resistant steel alloys and comprises a jacket 50 of thermal insulation.

Illustrative Examples of the Invention

In this application and accompanying drawings there is shown and described a preferred embodiment of the invention and suggested various alternative and modifications thereof, but it is to be understood that these are not intended to be exhaustive and that other changes and modifications can be made within the scope of the invention. These suggestions herein are selected and included for purposes of illustration in order that others skilled in the art will more fully understand the invention and the principles thereof and will be able to modify it and embody it in a variety of forms, each as may be best suited in the condition of a particular case.

Example 1

Glass heated to about 580°C is moved at a rate of 10 cm/sec across the apparatus shown in Figure 4. The temperature of the gas inlet duct is maintained at a temperature of about 300°C, by blowing appropriately heated or cooled air through the temperature control duct. The first deposition region reached by the glass is supplied with a gas mixture of the following composition (in mole percent):

1,1,2,2 tetramethyldisilane	0.7%
tetramethyltin	1.4%
bromotrifluoromethane	2.0%
dry air	balance

The second deposition region is supplied with a gas mixture of the following composition (in mole percent):

tetramethyltin	1.6%
bromotrifluoromethane	3.0%
dry air	balance

The flow rates of these gas mixtures are adjusted so that the average duration of contact between a given element of the gas mixtur and the glass surface is about 0.2 seconds.

The resulting coated glass is color-neutral in appearance, in reflected daylight. It has a visible reflectivity of 15%, and no visible haze. The infrared reflectivity is 90% at a 10 micron wavelength. The electrical resistance is measured

to be 5 ohms per square. The coating is about 0.5 microns thick.

Example 2

The deposition described in Example 1 is repeated, the only difference being the composition of the gas mixture supplied to the first deposition region:

1,2 dimethyldisilane	0.4%
1,1,2 trimethyldisilane	0.3%
1,1,2,2 tetramethyldisilane	about 0.02%
tetramethyltin	1.5%
bromotrifluoromethane	2.0%
dry air	balance

The properties of the resulting product are indistinguisable from those of Example 1.

Samples of these coated glasses have been subject to Auger chemical analysis of the coating composition along with ion sputter-etching to reveal their chemical composition versus thickness. Figure 5 shows the resulting chemical composition profile of the deposit over the region in which it varies. Near the glass surface the deposit is mainly silicon dioxide, with about one silicon atom out of eight being replaced by tin. As the distance away from the glass surface increases, the tin concentration increases and the silicon concentration decreases, so that by distances greater than 0.18 micron from the glass surface, the deposit becomes tin oxide, with about 1.5 percent of the oxygen replaced by the fluorine. Using Figure 3, the silicon-tin composition profile is converted to a refractive index versus distance profile, which is also plotted in Figure 5. These results confirm the ability of the disclosed process to produce the desired variation of refractive index through the thickness of the deposited film.

Example 3

A tin oxide coating is placed on a glass substrate at different thicknesses (the glass substrate is first coated with an ultra-thin film of silicon dioxide to provide an amorphous, haze-inhibiting surface.)

Thickness of Tin Oxide	*Iridescence Visibility*
0.3 micron	strong
0.6 micron	distinct, but weaker
0.9 micron	barely detectable except in fluorescent light
1.3 micron	weak, even in fluorescent light

The latt r two materials are not a sth tically objectionable for architectural use, confirming the visual color saturation scale used to evaluate the designs.

In order to provide the most effective suppression of iridescent color, it is d sirable that the refractive index of the initial deposit match closely that of the glass substrate, preferably to within ±.04, or more preferably to within ±.02 refractive index units. In order to achieve this match, one varies the parameters of the deposition, particularly the ratio of tin to silicon atoms in the inlet gas. As an example of such variation, Figure 6 shows the variation of refractive index in the initial deposit from tetramethyltin plus 1,1,2,2 tetramethyldisilane gas mixtures, as a function of gas composition. The other parameters for these depositions were fixed as in Example 1. Figure 6 shows, for example, that an initial deposit of refractive index 1.52 (appropriate to match usual window glass refractive indices) is produced by a gas composition of equal numbers of silicon and tin atoms. Matching to 1.52±.02 is achieved when the gas composition is kept between 47 and 52 atomic per cent of tin. While these exact numbers may differ somewhat in other conditions of deposition such as other temperatures or other compounds, it is a matter of routine experimentation to establish calibration curves such as Figure 6, in order to produce a suitable match of refractive indices between the substrate and the initially deposited coating composition.

It is to be noted that the reflection of light from the surface of the coated products of Example 3 is about 16 to 17%, i.e. about 10% higher than that from the coated glass in Examples 1 and 2 which do have a graded undercoat according to the invention.

It is also to be understood that the following claims are intended to cover all of the generic and specific features of the invention herein described and all statements of the scope of the invention which might be said to fall therebetween.

Claims

1. A process for continuous coating of a substrate by a film formed of reactive components of a gas mixture in which properties of the coating vary continuously through the thickness of said film, said process comprising the steps of:

(a) flowing said gas mixture through a reaction zone defined by a flow path for said reactive components contiguous to, parallel with and bound by, a surface of the substrate

(b) depositing, preferentially, a reaction product derived from a more reactive component of said mixture on a portion of said surface exposed earlier to said gas mixture,

(c) depositing, preferentially, a reaction product derived from a less reactive component of said mixture on a portion of said surface exposed later to said gas mixture, and

(d) moving said substrate surface through said reaction zone in a direction parallel to said flow path to obtain a change in the composition of said coating through ut the thickness of said coating, as said substrate emerges from said reaction zone.

2. A process as in Claim 1 in which said substrat is composed of glass.

3. A process as in Claim 1 in which said

reaction products are produced by reaction of said gases induced by heat from said substrate.

4. A process as in Claim 1 in which refractive index varies continuously from bottom to top through said coating.

5. A process as in Claim 4 in which said gas mixture includes volatile silicon and tin compounds and an oxidizing gas.

6. A process as in Claim 5 in which said gas mixture includes at least one partially alkylated polysilane, an organotin vapor, and an oxidizing gas.

7. A process as in Claim 6 in which said gas mixture contains at least one of methyldisilane and tetramethyltin.

8. A process as in Claim 7 in which said gas mixture contains 1,1,2,2 tetramethyldisilane; 1,1,2 trimethyldisilane; 1,2 dimethyldisilane or mixtures thereof.

9. A process as in Claim 2 in which refractive index varies continuously from bottom to top through said coating.

10. A process as in Claim 2 in which said gas mixture includes volatile silicon and tin compounds and an oxidizing gas.

11. A process as in Claim 2 in which said gas mixture includes at least one partially alkylated polysilane, an organotin vapor, and an oxidizing gas.

12. A process as in Claim 2 in which said gas mixture contains at least one methyldisilane and tetramethyltin.

13. A process as in Claim 10 in which said gas mixture contains 1,1,2,2 tetramethyldisilane, $HMe_2SiSiMe_2H$; 1,1,2 trimethyldisilane $H_2MeSiSiMe_2H$; 1,2 dimethyldisilane $H_2MeSiSiMeH_2$ or mixtures thereof.

14. A process as in Claim 2 in which said reaction products are produced by reaction of said gases induced by heat from said substrate.

15. A process as in Claim 3 in which refractive index varies continuously from bottom to top through said coating.

16. A process as defined in Claim 10 wherein the proportions of said reactive components are so selected to achieve a coating composition proximate to said substrate of at least 60% SiO_2 and a coating composition most remote from said substrate of at least 95% tin oxide.

17. A process for forming on a substrate, a thin coating, which has a changing composition from a predominantly first coating composition nearest the substrate to a predominantly second coating composition more remote from the substrate, said process comprising the steps of:

(1) introducing into a first end of a reaction chamber and out th other end of said chamber a mixture of a first reactant gas from which said first coating compound is formed,

a second reactant gas from which said second coating compound is formed, and

a third gas which forms means to react with each of said reactant gas s to form said coating compounds,

wherein said first reactant gas reacts at a substantially different rate with said third gas, than does said second reactant gas, the different rate of reaction with said third gas forming means to provide a difference in relative concentration of said reactant gases from one end of said chamber to the other and to provide different quantities of said coating compounds from one end to another; and

(2) continuously passing a substrate to be coated through said reaction chamber from said first end of the chamber to said other end of the chamber; and

(3) coating said substrate with a progressively changing composition as it moves through said chamber, said composition formed by depositing said coating compounds said compositions indicative of the relative reactivity and concentration of said reactant gases along said chamber.

18. A process as defined in Claims 1, 2, 3, 12, 13, 16 or 17 wherein said reaction products are deposited at such a rate that said change in the coating composition is monotonic resulting in a gradual increase of the refractive index of said coating as the thickness of said coating on said substrate increases.

19. A process as defined in Claims 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 16, or 17 comprising the step of terminating said coating operation with an infra-red reflective overlay of tin oxide anc wherein the total coating thickness is from about 0.1 to 1.0 micron thick.

20. A process as defined in Claims 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 13, 14, 16, or 17 wherein said coating is of such a thickness that it forms means to suppress visible irridescence, on the surface of a product of said process, as defined by a maximum Color Index value of about 12.

21. A transparent glass product substantially free of iridescent appearance, having a glass substrate bearing a coating which is substantially uniform across the surface area thereof, said coating consisting of

(a) a lower coating zone comprising a material formed of at least two components which is characterized by a gradual change from a first composition proximate to said substrate having a relatively high proportion of a first component to a second composition more remote from said substrate having a relatively large proportion of said second component; and

(b) an upper coating zone having a refractive index substantially the same as that of said second component.

22. A product as defined in Claim 21 wherein said lower coating zone is substantially linear with respect to its molecular proportion of said first component, as a function of distance from the glass substrate.

23. A product as d fined in Claim 21 wherein said first component is SiO_2, said second component is SnO_2, and said upper coating zone is fluorine-dop d tin oxide.

24. A product as defined in Claim 23, wherein the coating is less than one micron thick.

25. Apparatus for forming a continuous coating of progressively changing composition on heated glass, said apparatus comprising, in addition to means to support said glass, to maintain in at an elevated temperature, and to move it along a continuous processing path,

the improvement wherein there is provided a reaction zone, having at one end thereof, a port means at a first station to introduce and distribute a gaseous reaction mixture comprising reactants which form products that deposit on said glass at different rates, a flow path forming a reaction zone wherein said mixture flows along said glass surface, port means at a second station to remove residual gaseous reaction mixture, said second station being relatively positioned along said processing path with respect to said first station that said heated glass forms means to provide sufficient energy to said gaseous reaction mixture to achieve a substantial difference in composition between the reaction gas mixture composition between said first station and said second station.

26. Apparatus as defined in Claim 25 wherein said ports are mounted below said glass, and said glass forms the upper boundary of said processing path.

27. Apparatus as defined in Claim 25 wherein said ports are slit-like openings arranged parallel to one another and substantially normal to the flow path of said glass.

28. Apparatus as defined in Claim 26 wherein said apparatus is adapted to fit between adjacent support rolls of the lehr of a float-glass manufacturing line and comprises means to move said apparatus vertically and horizontally to facilitate positioning said apparatus, and the removal of said apparatus from said lehr.

29. Apparatus as defined in Claim 25 wherein said inlet and outlet ports communicate with inlet and outlet ducts, each of which share a common temperature control duct, adapted to carry a heat-transfer medium which stabilizes and controls the temperature of the apparatus, and which forms a cooling means for gas in the outlet duct and heating means for gas in the inlet duct, all said ducts forming an integral unit adapted to fit between rolls of a lehr in a float glass line and beneath a glass substrate carried on said rolls.

30. Apparatus as defined in Claim 25 comprising additionally, a second coating apparatus mounted in series, within said lehr, said second apparatus forming means to provide an additional coating to said coating of progressively-changing composition.

31. Apparatus for forming a continuous coating of progressively changing composition on heated glass, constructed and adapted to operate substantially as hereinbefore described with reference to the accompanying drawings.

32. A process for continuous coating of a substrate, substantially as hereinbefore described with reference to the accompanying drawings.

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